Australian Journal of Basic and Applied Sciences, 7(10): 381-387, 2013
ISSN 1991-8178

Computer Aided Simulation of a 4BL Engineering Problem Using Matlab

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Abstract: The synthesis and analysis of four bar mechanisms is well known classical design problem. However limitations to the classical theory of this problem potentially limit its application to certain real world problems by virtue of the small number of precision points and unspecified order. In this paper we describe an improved computer aided simulator (CAS) for visualizing a four bar link (4BL – simple movable closed chain linkage) mechanism engineering problem using MATLAB software. The aim is to facilitate the analysis, dynamic simulation of the four-bar mechanisms. First, a brief review of some of the current computer-aided learning software for four-bar mechanisms is presented. These software packages provide two-dimensional visualization and computational capabilities necessary to synthesize and analyze four-bar mechanisms. However, to date, no readily available and effective tools exist to aid in the understanding of 4BL mechanisms due to misinterpretation of data. The paper also reviews the kinematics of four-bar mechanisms as they pertain to their geometric modelling followed by the design approach of the graphical MATLAB CAS for four-bar mechanisms. A preliminary validation test using pre and postest questionnaires and focus group discussion with student participation in using the MATLAB CAS tool has facilitated in visualizing the engineering concepts of 4BL mechanism at UNITEN.

Key words: Simulation, education, engineering, learning and 4BL mechanism.

INTRODUCTION

Educationist, software and hardware developers are designing new and highly engaging technologies to aid in improving the learning process of a particular subject. One of the highly engaging technologies is multimedia. Interactive learning with multimedia is increasingly powerful in education due to its benefits in terms of innovative pedagogy and its positive impact on student outcomes. As a consequence in this area, economical personal computers and various software packages have led to the concept of Computer Aided Learning (CAL) (Manjit, 2007). With the emergence of CAL, complex dynamic information could be grasped by students in a much quicker time as compared to the traditional fashion (static information). In engineering subjects such as mechanics dynamics, complex problems that needs computations such as dynamics and motion of rigid bodies needs higher level of understanding since the information is normally mixed with text, numbers, diagrams, charts, equations and formulas. For this reason numerous software tools have been developed to help students understand the concepts of engineering problems better (Huber and Dietmajer, 2010; Oleg, 2000; Kihonge et al, 2002; Manjit, 2003; 2008; 2009). In this research we design and simulated a 4BL simulation problem using MATLAB. A preliminary validation test of the 4BL design has facilitated potential users (first year mechanical engineering students) in visualizing the engineering concepts. The testing was enhanced by a laboratory session where the students and the lecturer teaching the subject matter had hands on practical on using the 4BL MATLAB tool. This paper is organized as follows: Section 2 covers the literature and basic theory of 4BL mechanism. Section 3 describes the design process approach. Section 4 shows the results and discussion of the impact of the proposed pedagogy. Finally section 5 presents a conclusion to summarize the main outcomes of this research.

Basic Theory of 4BL Mechanism:

One of the objectives of this research was to study and understand the motion of the 4BL mechanism and see how it could be simulated (Manjit, 2011). The purpose of this mechanism is to transmit motion and force from one location to another. The theory of this mechanism can be understood by the 4BL (which consists of four rigid bodies each attached to two others by single joints or pivots to form a closed loop) (Wikipedia, 2011) and (Oleg, 2000). This problem was chosen because in the past it was found that some students could not visualize its concepts in engineering at UNITEN. In addition we could not find any completed 2-D model of this problem in the present literatures. Some free available simulations found on the Internet (Fig. 1 and 2) however gave wrong results and misinterpreted the data and were not interactive enough. As such these simulations were not suitable and helpful for the students to learn.

To further explain, a 4BL or four-bar linkage is the simplest closed bar linkages that are important mechanisms found in machines. The kinematics and dynamics of 4BL are important topics in mechanical

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engineering. 4BL linkages are constructed from four links connected in a loop by four one degree of freedom joints. A joint may be either a revolute that is a hinged joint, denoted by ***R***, or a prismatic, as sliding joint, denoted by ***P***. The planar quadrilateral linkage is formed by four links and four revolute joints, denoted ***RRRR***. The slider-crank linkage is constructed from four links connected by three revolute and one prismatic joint, or ***RRRP***. The double slider is a ***PRRP*** linkage. One link of the chain is usually fixed, and is called the ground link, fixed link, or the frame. The two links connected to the frame are called the grounded links and are generally the input and output links of the system. The last link is the floating link, which is also called a coupler or connecting rod because it connects an input to the output.

The Grashof's condition for a planar quadrilateral linkage, which is a planar four-bar linkage constructed from four hinged joints, states: *If the sum of the shortest and longest link of a planar quadrilateral linkage is less than or equal to the sum of the remaining two links, then the shortest link can rotate fully with respect to a neighboring link*. For a four-bar linkage, the Grashof Condition is satisfied if ***S*+*L* ≤ *P*+*Q*** where ***S*** is the shortest link, ***L*** is the longest, and ***P*** and ***Q*** are the other links. When the Grashof condition is satisfied, at least one link will be completely rotatable. Figure 1 show the sketch of the 4BL mechanism which can be described by nine independent variables. The small triangles show revolute joints affixed to the ground, the open circles represent revolute joints that join two links, and the filled circle is the coupler point. Link 1 is the input link, the large shaded triangle is link 2, the coupler, link 3 is the output link, the follower and link 4 is the ground. Also shown are the offsets from the world origin and an angle that represents the angular offset of the coupler point.

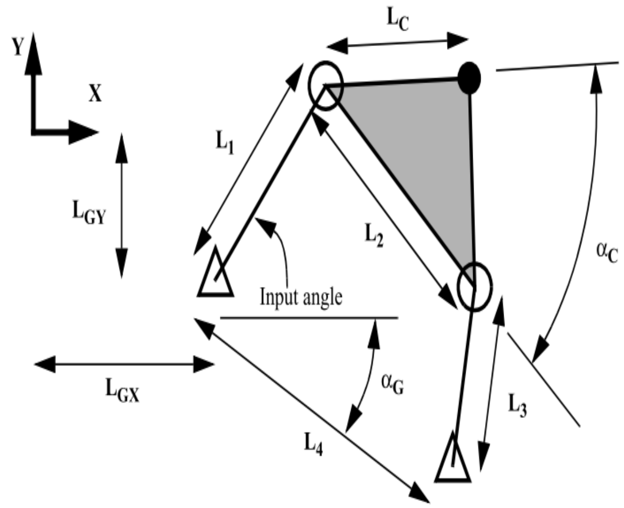

Fig. 1: Four bar mechanism.

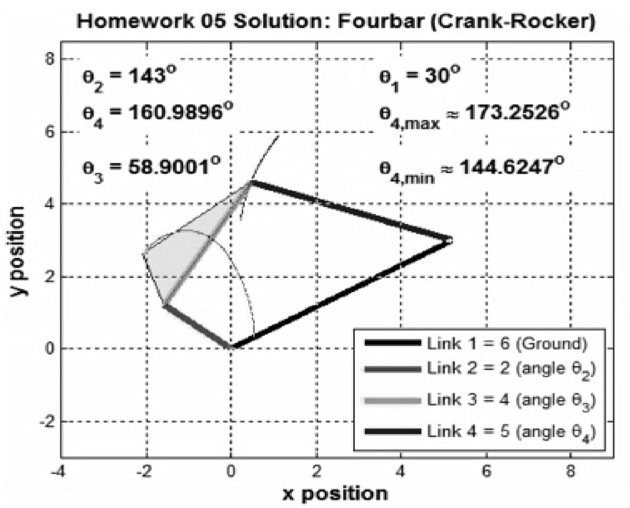

Fig. 2: Four bar mechanism software sample 1.

Figures 2 and 3 show examples of the software found using YouTube. However these softwares were not interactive enough for the students to learn as it does not allow them to input numeric values and see the simulation (merely video based simulation).

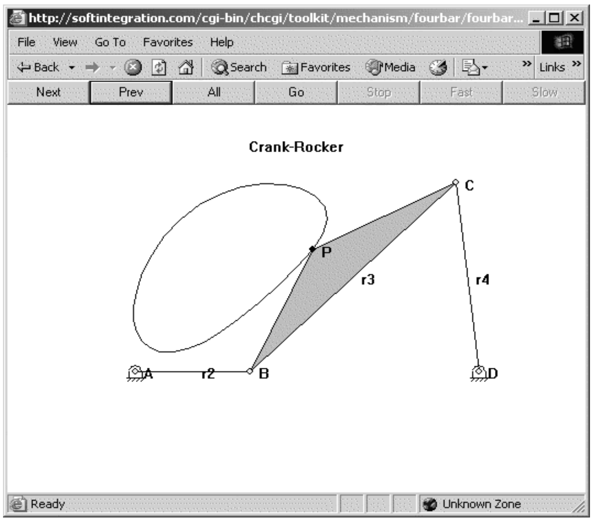

Fig. 3: Four bar mechanism software sample 2.

Methodology:

Computer based simulation tools has been employed by many higher learning instituions as an alternative to teaching engineering because it can be used to simulate and show realistic 2D to 3D models of a problem or process to simplify and explain the functioning of complex mechanisms. However a study conducted at the University of Rome stated that, "*although the integration between numerical computation and graphics leads to the generation of photo-realistic digital mock-ups, they are still far from the real context and the user has a limited interaction with them*" (Paolo, Valentine, and Pezzuti, 2010). Furthermore this limitation can generate problems (non-conformities, unexpected behavior and appearance, etc.) when the designed products have to be integrated in the real world. To overcome this disadvantage, the development of new software tools, based on the mixing between the real world and virtual objects, seems to be the futuristic to computer aided learning. This section describes the design approach and methodology used in simulating the 4BL mechanism followed by an explaination of how it can help students to vizualize and comprehend the problem while interacting with the simulation tool.

Most simulation of 4BL mechanisms that are available at present are designed using 2D graphics and may not be appropriate for visualization process due to the aforementioned reasons. In addition the workings solution of a given problem is not shown in details thus living the student to work on their own to understand. In our approach the student is able to interact with the 4BL mechanism in a real time 2D environment and is able to experiment the parameter updates of the animated 4BL by changing different values that meets grashofs law. As for the development of the 2D model, we used MATLAB with graphical user interface as the main platform. This simulation graphical tool was modified from the original design by John Hawkins (some features were removed and new ones added). Figure 4 shows the main interface of the 4BL simulation tool that was designed and enhanced in this research.

The simulation is a graphical tool to visualize 4BL mechanisms and the instant centers that are produced by the mechanisms, and plots the path/trail of the instant centers. The paths of the instant centers are shown in Fig. 5 (blue lines) for the mechanism and the inversion of the mechanism (switching the coupler link and the ground). The paths represent two curves, that when one roles on the other, produces the same motion as the original 4-bar coupler that made them, e.g. the 4-bar can be synthesized by a 2-bar mechanism consisting of only the fixed and moving path. The moving path curve will have two points on it that travel in circles, just as the original coupler did on the 4-bar.

The user can select from eight different types of 4-bars, e.g. cranks and rockers or combinations of the two. Additionally the user can specify any link length of interest, numerically with slider bars, and do so while the animation is running (by pressing the "*Reset lengths*" button) shown in Fig. 5. The "*Run*" button allows the user to see the simulation after manipulating the parameters of the input angle and link lengths. The user may also save the animated image as a "*jpeg*" file at any time desired by clicking on the "*Save as image*" button. This could be useful for future reference.

In terms of graphical user interface and the simplicity of data manipulation we adopted the slider bar button. The slider bar button could be used to adjust the animation speed and input angle specification. When the user clicks the "*Pause*" button, the input angle may be specified by dragging the slider to move the mechanism. Appropriate colours were used to draw the students attention. For example the two small green triangles (Fig. 5) show revolute joints affixed to the ground, the open circles represent revolute joints that join two links, instant paths are shown in “*blue colored curves*” and the red lines are the linkages.

In order to gauge the level of effectiveness of the simulation tool, the user has the opportunity to apply the knowledge gained through the lesson by simply going through the prepared exercises as typically shown in Fig. 6 - 8. Three types of questionnaires are available namely multiple choices, true/false and fill in the blanks. The exercises are design in such a way that the students can interact with the system and keep on trying until they obtain the correct answer to all the wrong ones only.

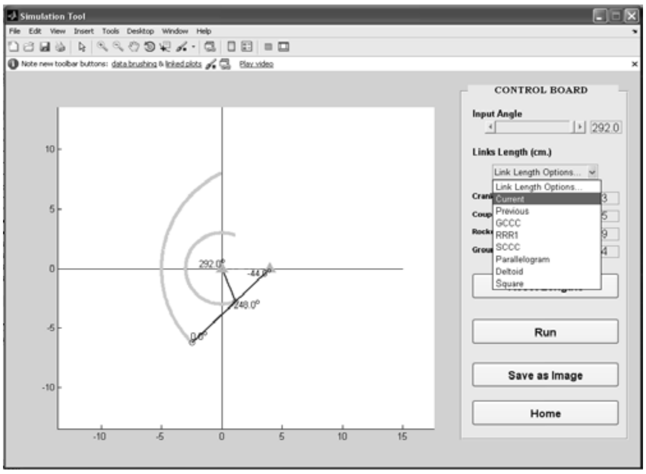

Fig. 4: The main interface of the 4BL simulation tool.

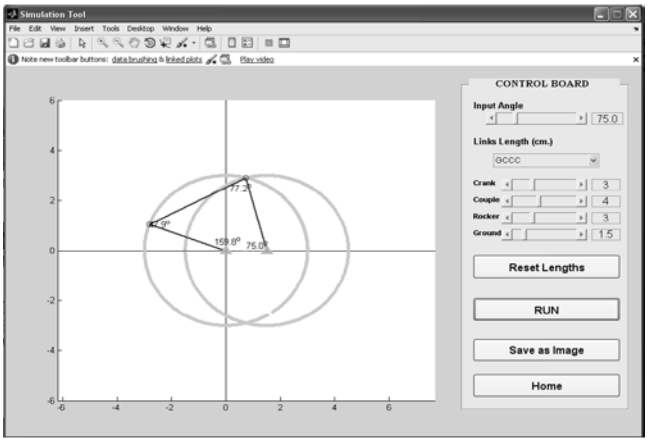

Fig. 5: The paths of the instant centers.

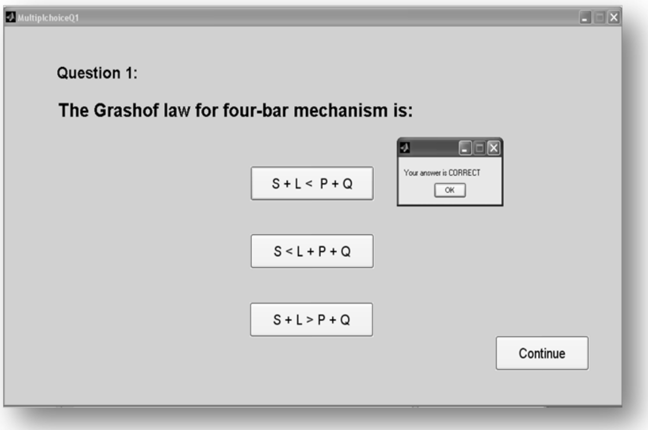

Fig. 6: Multiple choice questions.

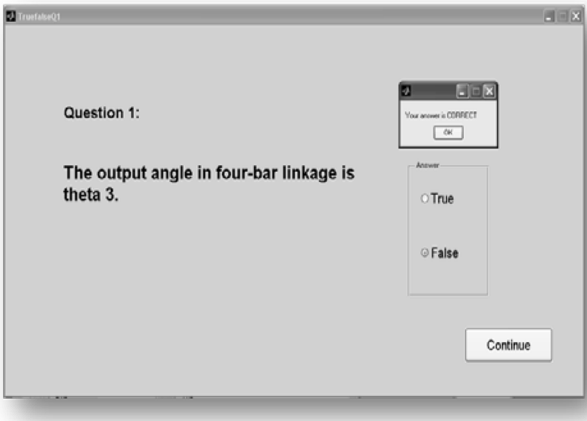

Fig. 7: True and False questions.

Fig. 8: Fill in the blanks questions.

On completion of the design, fifty-five students participated in the one week trial of the prototype of the MATLAB CAS tool, in August 2011. This followed an informal evaluation of an earlier, traditional based teaching by the subject matter instructor. As part of the one week trial of the MATLAB CAS tool, students completed a pre and post test questionnaire. The questionnaires consisted of three sections:

(a) Interest in, and knowledge of, aspects of the 4BL mechanism;
(b) Access and experience with computers; and
(c) Views of traditional teaching and learning.

Answers to questionnaires in section (a) required a combination of ratings on 5 point Likert scales (1 strongly disagree to 5 strongly agree) and open ended questions. Section (b) contained some yes/no questions (for example, do you have access to computer at home?) as well as questions requiring an answer on 4 or 5 point scales. All questions on views of traditional teaching and learning used 5 point Likert scales.

The MATLAB CAS tool was introduced to the students following six weeks traditional course lectures. The pre test questionnaires were administrated in the class in which the MATLAB CAS tool was introduced. Students were informed that the questionnaires were not a test and that the results would be used to provide information about how the MATLAB CAS tool could be improved. Students were advised that they would receive another set of questionnaire at the middle of the six weeks course. It was not pointed out that this would be the same questionnaire as the students might then be inclined to try to remember their answers to the first survey. The post test questionnaires were administrated in the class about six weeks later, after the MATLAB CAS tool had been designed and improved. As the mid-term semester break was nearing, some students had gone home earlier thus attendance was not high enough in the initial class. Comparisons between pre and post test responses were made using t-tests for related groups.

A focus group of 11 students was also conducted by an academic member. During this time the focus group was asked their overall impression and understanding of the MATLAB CAS tool and their suggestions for improving the tool.

RESULTS AND DISCUSSION

The majority of the students (80%) had access to a personal computer at home, rated their computer skills as average in using computer based learning software in their learning (59%), and had used at least one application at the foundation degree level course.

Pre and post questionnaire were available for 37 students (67%) as 18 students failed to complete a questionnaire at the end of the pilot study. Some students who failed to complete the questionnaire were added in the focus group. A comparison between the pre-questionnaire responses by those who completed both questionnaires and those students who only completed the first questionnaire revealed no significant differences in the responses of the two groups.

Comparisons of students' pre and post test survey responses showed that after the students who had used the MATLAB CAS simulation tool rated their knowledge (t=-4.46, df=35, p<0.001) (see Table 1). Students also rated their interest in using the MATLAB CAS simulation tool as significantly greater after understanding the concepts of 4BL mechanism (t=-2.27, df=36, p<0.05).

To determine whether the MATLAB CAS simulation tool aided the students to visualize the 4BL mechanisms, pre and post test questionnaires asked students to solve selected problems of the subject matter. In the pre test questionnaire average number of score was 2.6 with 25% of students able to answer at least two questions correctly out of four questions. This compared to a mean of 3.2 in the post test questionnaire with only 7% of students unable to answer two questions correctly.

The evaluation results presented here represents the preliminary phase of the assessment, examining the first group of students who participated. The results are motivating. However further formative evaluation results are required to see whether the results hold and are sustained across time and over different settings and with different student group is planned. On the basis of these results it is suggested that the MATLAB CAS simulation tool helps students in the visualization process. Additionally it allows students to interact with the MATLAB CAS simulation tool to put knowledge gain in class into practice. The achievement of these learning outcomes was supported by the results from the evaluation, which showed that at the completion of using the MATLAB CAS simulation tool students rated and demonstrated, that their knowledge about 4BL mechanisms and applying the right equations in solving the problem has significantly increased.

Table. 1: Mean and standard deviations of responses to the pre and post test questionnaires.

Question	Mean Pre Survey (Standard deviation)		Mean Post Survey (Standard deviation)	
How would you rate your present knowledge on the 4BL mechanism?	3.1	(.54)	3.4**	(.64)
How would you rate your present knowledge on the way the 4BL mechanism topic as learnt from the textbook?	3.1	(.80)	3.5**	(.69)
How would you rate your present knowledge on the way the 4BL mechanism topic as taught by the instructor?	2.9	(.70)	3.4**	(.72)
Scale used 1 = very poor; 2 = poor; 3 = average; 4 = good; 5 = very good				
Learning the 4BL topic is easy?	3.7	(.62)	3.8*	(.46)
In general I am interested in using the MATLAB CAS simulation tool?	3.0	(.10)	2.8	(.76)
I found the MATLAB CAS simulation tool to be useful and easy to use?	3.4	(.93)	3.2	(.96)
The MATLAB CAS simulation tool helped me in visualizing the 4BL mechanism better?	2.6	(.87)	2.4*	(.73)
I solve similar problems better after using the MATLAB CAS simulation tool?	2.5	(.10)	2.6	(.87)
Scale used 1 = strongly disagree; 2 = disagree; 3 = neutral; 4 = agree;5 = strongly agree				
Items where there were significant difference between pre and post test questionnaires *p<0.05, **p<0.01				

Conclusions:

The employment of computer software tools for modelling and simulating the operation and functions of mechanical engineering mechanisms is an essential pedagogic complement to modern teaching and learning. The study undertaken in this research is an important contribution in the educational domain of information technology and students and instructors of mechanical engineering department of UNITEN. Previous experience of instructors teaching the 4BL mechanism problem at UNITEN found that students had difficulty in understanding the basic concepts and applying the right equations. To solve this problem, the researchers propose a pedagogic approach based on the use of the MATLAB CAS simulation tool to help students to comprehend and visualize the motions of the 4BL problem in an interactive manner. The evaluations results of the MATLAB CAS simulation tool revealed that the tool was useful and could help the students in understanding the topic better.

The design of the graphical user interface using MATLAB was a great help to students in interacting with the MATLAB CAS simulation tool as the students were familiar with such user interfaces due to their experience of surfing the Internet for related information. The use of appropriate colors and labels in the tool also helped students to grasp the concepts of 4BL mechanisms faster as opposed to the traditional method of learning. The inclusion of the three types of questionnaires (multiple choices, true/false and fill in the blanks) in the MATLAB CAS simulation tool to gauge the students understanding was also helpful as similar existing tools available on the Internet do not provide such features.

Further work is in progress in simulating the problem designed in this research using augmented reality as this technology allows users to see the real world at the same time as virtual imagery attached to real locations and objects.

ACKNOWLEDGMENTS

We would like to acknowledge the considerable contributions of Assoc. Prof. Dr. Faris Tarlochan from the Mechanical Engineering Dept, UNITEN for explaining the concepts of the 4BL mechanism. Thanks are also due to Dr. Kirandeep Kaur for proof reading this paper.

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